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Soil Stabilization for Road Construction: Comparative Analysis of a Three-Prong Approach

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Abstract. The paper aim to assess and compare the stabilizing effect of three materials, cement, sodium chloride and brick dust on clay soil found at locations during road construction. To achieve this, the powder forms of samples of each of the three materials are mixed to clay soils in various percentages of 2%, 6%, 10% and 14%. The moisture content, specific gravity, sieve analysis, atterberg limit tests were carried out to classify the soil using the AASHTO classification system. Based on the results obtained the soil sample corresponds to group A-2-7 (Clayey Sand) and poorly graded sand with clay (SP-SC) soil type for use as drainage and subgrade material. According to the classification, this is acceptable for stabilization of soil. Specific gravity, sieve analysis, atterberg limit, compaction, California bearing ratio (CBR), swell index were carried out on the soil with and without the addition of (cement, sodium chloride, brick dust). The results showed improvement in the maximum dry density value on addition of cement, sodium chloride with gradual increase from 2% to 14%, the brick dust content showed gradual increase up to 6% and after which it started to decrease at 10% and 14%. The three materials are therefore recommended as stabilizing agents for use in road construction where clay soils play a significant part in early deterioration of this important fulcrum of Nigeria national development.

Keywords: soil stabilization, silty clay soil, cement, sodium chloride and brick dust

1. Introduction

Soil may be defined as the natural loose surface material of the earth that supports plant growth when dug or ploughed. Clay is also a natural material composed mainly of fine grain materials that consist of tiny particles that have plastic and adhesive properties. Clay possesses small voids and pores which make it possible to retain water and water tend to cause the expansion and shrinkage, which could lead to settlement.

When exposed to water in high quantity, clay tends to soften and liquefy and this property of clay makes construction difficult due to its low strength and stiffness. This has posed serious challenges in geotechnical engineering because weak soil may cause damage to the foundation of buildings and cause cracks to buildings and along road pavement.

Soil stabilization may be defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of the soil. Soil stabilization generally refers to the procedure in which a special soil, cementing material, or other chemical materials are added to a natural soil to improve one or more of its properties. Stabilization therefore looks at the various methods employed for modifying the properties of a soil to improve its engineering performance. One may achieve soil stabilization through mechanically mixing the natural soil and stabilizing material together so as to achieve a homogeneous mix or by adding stabilizing material to

undisturbed soil deposit and obtaining interaction by letting it permeate through soil voids. When soil is stabilized by use of additives it improves the properties of less-desirable road soils. When used these stabilizing agents can improve and maintain soil moisture content, increase soil particle cohesion and serve as cementing and water proofing agents.

Since foundation of any structure including road is a critical aspect of the structure in terms of load transfer to the earth, it is usually a difficult problem in civil engineering works when the sub-grade is



found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase. The most common methods of soil stabilization of clay soils in pavement work are cement and lime stabilization. Lime or calcium carbonate is oldest traditional chemical stabilizer used for soil stabilization.

The work presented in this paper is an addition to the application of chemical stabilization technique, by comparing the use of sodium chloride (NaCl), cement, brick dust at different percentages to the clay soil gotten from in a borrow pit in a University environment in Ota, Ogun state. The concentrations by weight of each of the stabilizers used are 2%, 6%, 10%, and 14%. The sodium chloride (NaCl), cement and the brick dust used were all open market purchased from Abeokuta.

To underscore the challenge, it is necessary to understand that Nigerian roads are characterized with potholes, longitudinal cracks and lots of other pavement defects known to road construction. In Nigeria you can hardly travel a mile without coming across potholes which have contributed to greatly to the high rate of accidents occurrence and a dip on the nation's economic development. All roads designed and built have a stipulated design life but roads most times fail long before the expected date, some fail immediately after construction others after heavy flooding, some stay up to half of its life cycle while others last to its full life expectancy with proper maintenance. A major cause of these failures is the increase in water content of granular subgrade materials. Since soil stabilization is generally any method used to improving the ability of the soil to carry load, California Bearing Ratio (CBR) values of soil and hence render it able to resist the loads and adverse effects of construction activities, therefore, this study is to conduct tests to ascertain the best additive amongst cement, sodium chloride or brick dust that improves the geotechnical properties of clay soil.

The use of waste products or by products of industrial production is now being used as it helps to reduce carbon foot print. This justifies the use of brick dusts as alternative material to cement and salt in soil stabilization when it is understood that it contribute to saving of time used for total excavation and replacement as was done in the past in case of weak soils. However, before decisions are made to stabilize soil for Engineering purpose, it is necessary to understand the nature of the soil by carrying out prescribed tests on the soil sample.

(a) SOIL

Soil can be looked at as consisting of a wide range of relatively smaller particles derived from a parent rock through mechanical weathering process that includes air and/or abrasion, freeze-thaw cycles, temperature changes, plant and animal activity such as burrowing and by chemical weathering process that include oxidation and carbonation^[1]. Soil can also be defined as the solid material on the Earth's surface that results from the interaction of weathering and biological activity on the parent material or underlying hard rock. Different people define soil to suit their purpose. To a geologist it represents the products of past surface processes; to a pedologist it represents currently occurring physical and chemical processes; to an engineer it is a material that can be built on (foundations to buildings, bridges), building of (tunnels, culverts, basements), building of (roads, runways, embankments, dams) and supporting (retaining walls, quays)^[2]. It was also noted by Sabat in 2012 that for an Engineer, there are a number of techniques available to improve the engineering properties of soil to make it suitable for construction purposes. These include stabilization using dust/powder like waste materials with and without a binder like lime, cement etc. Others include Quarry Dust^[3], marble dust^{[4],[5],[6],[7]}, baryte powder^[8], pyroclastic dust^[9] and brick powder^[10] are some of the prominent dust/powder like waste materials which have been successfully utilized for stabilization of expansive soil.

(b) CLAY SOIL

Clay has the smallest particle size of any soil type, with individual particles being so small that they can only be viewed by an electron microscope. This allows a large quantity of clay particles to exist in

a relatively small space, without the gaps that would normally be present between larger soil particles. Because of the small particle size of clay soils, the structure of clay-heavy soil tends to be very dense.

(c) CLAY MINERALOGY

Clay refers to naturally occurring material composed mainly of fine-grained minerals, which is generally plastic in nature at appropriate water contents and will harden when fired or dried. The minerals found in clay are generally silicates less than 2 microns (one millionth of a meter) in size, about the same size as a virus. Clay is very abundant at the earth surface therefore they tend to form rocks known as shales and are a major component in nearly all sedimentary rocks. The small size of the particles of clay are their unique crystal structures giving clay minerals special properties, including cation exchange capabilities, plastic behavior when wet, catalytic abilities, swelling behavior and low permeability.

Clay minerals are hydrous silicates, largely of aluminum, magnesium, and iron that on heating lose adsorbed and constitutional water and yield refractory material at high temperatures. Plasticity is a characteristic of clay minerals and is largely due to an affinity of the clay surface for water, resulting from a net negative charge on the surface of a clay particle that causes it to adsorb water and other fluids. Clay minerals can therefore profoundly affect a soil's engineering behavior, even when present in small quantities. As the clay content of a soil sample increases, the influence the clay fraction will have on the behaviour of the sample also increases. The strong influence of clay minerals on soil behaviour can be illustrated by the addition of bentonite to a granular soil. Bentonite is a clay mineral composed largely of the clay mineral sodium montmorillonite. In 2012, Sabat conducted series of test and concluded that the addition of brick dust decrease liquid limit, plastic limit, plasticity index, optimum moisture content, maximum dry density and angle of internal friction of clay soil.

In 2012, Mukesh and Patel studied materials and soils derived from the Feuerletten (Keuper) and Amaltheenton (Jura) formations along the new Nuernberg Ingolstadt railway line (Germany) and mentioned earlier work by Ismail in 2004 on this. The work included petrological, mineralogical studies and scanning electron microscope materials related to road construction using lime (10%), cement (10%), and lime/cement (2.5%/7.5%). It was determined that consistency limits, with proper compaction, that by increasing the optimum moisture content (%) of the treated soil, the density (g/cm^3) decreased. The cohesion and the friction angle of the improved materials increased for all the treated mixtures. In case of the lime materials, uniaxial strength increased strongly using lime and cement together. For the Amaltheenton formation, uniaxial strength increased strongly with cement alone. The author also noticed that the loss of weight during freezing and thawing test was low and depended on the material type.

The work by Ampera and Aydogmust in 2005 treated Chemnitz clayey soil (Association of State Highway and Transportation Officials (AASHTO) using lime at (2, 4, and 6%) stabilization and cement at (3, 6, and 9%). The authors conducted compaction-unconfined compressive strength and direct shear test on untreated and treated specimens. They concluded that the strength of cement treated soil was generally greater than the lime treated soil.

Also the work by Tamadher and Mohamed in 2014, aimed to investigate the effect of adding chloride salts including (NaCl , MgCl_2 , and CaCl_2) on the engineering properties of silty clay soil. Three amount percentage of salt (2%, 4%, and 8%) were added to the soil to study the effect of salts on the compaction characteristics, atterberg limits, and unconfined compressive strength. The results showed that the increase in the percentage of each of the chloride salts increased the maximum dry density and decreased the optimum water content. The liquid limit, plastic limit, and plasticity index decreased with increasing salt content. Also the results showed that the unconfined compressive strength increased when the salt content increased too.

The researchers listed above investigated the use of cement, salt and brick dust at between 2 – 8% in soil stabilization, the current effort therefore extended the argument up to 14% to observe the effect of such increase on the engineering properties of soil.

(d) Cement

Cement has been described as a finely ground inorganic material ^[14], which when mixed with water, form a paste which sets and hardens by means of hydration reaction and processes and retains its strength and stability even under water. Ordinary Portland cement is the commonest type in use. The raw material from which it is made is lime, silica, alumina and iron oxide. These constituents are crushed and blended in correct proportions and burnt in a rotary kiln. The clinker is cooled, mixed with gypsum and ground to a fine powder to give cement. The main chemical compounds in cement are calcium silicates and aluminates.

Cement is highly used as a stabilizing material for soils, particularly for the construction of highways and earth dams. It can be used to stabilize sandy and clayey soils. As in the case of lime, the cement has an effect to decrease the liquid limit and to increase the plasticity index and workability of clayey soils

(e) Salt

Soil water salinity can affect soil physical properties by causing fine particles to bind together into aggregates. This process is known as flocculation and is beneficial in terms of modifying the required engineering properties of the soil. Taking into consideration the abundance of salt and economic viability, the use of sodium chloride is preferable. Sodium has the opposite effect of salinity on soils. The forces that bind clay particles together are disrupted when too many large sodium ions come between them. When this separation occurs, the clay particles expand, causing swelling and soil dispersion. In a study by Işık and Berrin in 2009, it is stated, that the performance of the gypsum act as an additive for the treatment of the clay soils by means of swell potential and strength.

The effect of adding chloride salts including (NaCl, MgCl₂, and CaCl₂) on the engineering properties of silty clay soil has been studied. The results showed that the increase in the percentage of each of the chloride salts increased the maximum dry density and decreased the optimum water content. The liquid limit, plastic limit, and plasticity index is known to decreased with increasing salt content. Also the results showed that the unconfined compressive strength increased when the salt content increased too.

(f) Brick dust

Brick dust is known to increase the amorphous silica and alumina present in soil especially as burnt clay dust. According to ^[16], clay bricks when fired at a temperature below 950°C if ground into fine powder results in a pozzolanic reaction when combined with lime because of the presence of silica and alumina. It is however necessary to note that raw clay on its own has no pozzolanic value. A general rule is that clay, though the composition is source specific, should contain 20-30% alumina, 50-60% silica and the remainder consisting of magnesia carbonate, calcium carbonate and iron oxide.

Bhavsar, Joshi, Shrof and Patel in 2014, studied the use of industrial waste such as brick dust in soil stabilization, the advantages presented include; proper disposal of such waste, saving biodiversity, increasing soil properties such as strength, reduce permeability etc., preservation of natural soil and design and construction of economic structures. The work concludes a positive result with the use of brick dust on black cotton soil where increasing content of brick dust reduces the swelling index and hence stabilizing the soil.

Brick dust is locally available material which is formed from the crushing of industrial clay bricks into dust particles. This admixture is available and sold in the open market in Nigeria, which include Ota, though various companies in Lagos produce them as building bricks. The work by Kumar, Kumar and Prakash in 2016, also reported decrease in swelling index of clay soils when mixed with lime and brick dust due to decrease in plasticity of the soil as a result of the reduction in clay content of soil because of the replacement of the clay with brick dust.

2. Methodology

Clay soil samples, cement, sodium chloride, brick dust and water were used for this study. The clay soil samples were gotten from a borrow pit in Ota. The soil was collected at a depth not less than 1m from the ground. The sample was kept safe and packed in an air-tight sack bag to retain its natural moisture. The natural moisture contents of the samples were immediately determined on getting to the laboratory and the sample was kept to dry in the ovens in the soil laboratory of a Construction Company in Lagos state.

Marks were placed on them to indicate soil descriptions, sampling depths and dates of sampling. The samples were spread on different matting to facilitate air drying. All the clods and lumps in the samples were broken down and reduced to fine particles before performing various tests on them. The tests carried out were done under BS1377 ^[19] specification. The cement was gotten from the concrete laboratory of the Company, the sodium chloride was purchased from the local market, the brick dust was gotten from Ota Ogun state and crushed at the Company Laboratory, and portable water available in the laboratory was used for tests performed during this study.

The following tests and analyses were carried out in the laboratory according to ^[19] specification to:

(a) determine the index properties of the soil sample before stabilization

(i) natural moisture content

(ii) sieve analysis

(iii) atterberg Limits

(iv) specific gravity

(b) determine the strength properties of the clay soil sample before stabilization

(i) compaction

The analysis on the strength properties and index properties of the soil samples as in (a) and (b) above were carried out after soil stabilization with various percentages of cement, sodium chloride and brick dust. Microsoft Excel statistical package was used to analyze the data collected by comparing the results of different percentages used in the three approaches.

3. Results and Discussion

(i) Natural Soil Moisture Content

The summary of the result of the geotechnical properties of the natural soil is presented in table 1. The natural moisture content of the soil was found to be 10.3 as presented in the table on the geotechnical properties of natural soil.

Table 1: Geotechnical properties of natural soil

Natural moisture content (%)	10.3
Specific gravity (g/cm^3)	2.62
Liquid limit (%)	43.8
Plastic limit (%)	23.5
Plasticity index (%)	20.3
Maximum dry unit weight (kN/m^3)	16.7
Optimum moisture content (%)	17.1
Soaked California bearing ratio (%)	8

(ii) SIEVE ANALYSIS

In the particle size analysis of the sample, more than 6.18% of the soil sample passed the No. 200 sieve as shown in table 2. Using AASHTO classification, the soil belongs to the sub group A-2-7 (Clayey Sand) and poorly graded sand with clay (SP-SC).

Table 2: Particle size distribution of natural soil.

Sieve	Weight of sample	Percentage retained	Cumulative retained	%	Percent finer
7- 2.36	6.0	1.20	1.20	98.80	
14- 1.18	3.0	0.60	1.80	98.20	
25- 0.60	43.3	8.66	10.46	89.64	
36- 0.425	211.4	42.28	52.74	47.26	
52- 0.30	143.1	28.62	81.36	18.64	
100- 0.15	56.5	11.30	92.60	7.34	
200- 0.075	5.8	1.16	93.80	6.18	
-200 (T)	30.9	6.18	100	-	
Total	500.0		100		

SPECIFIC GRAVITY

Variation of the specific gravity test for the soil sample with changes in cement, sodium chloride and brick dust content are presented in Figure 1.

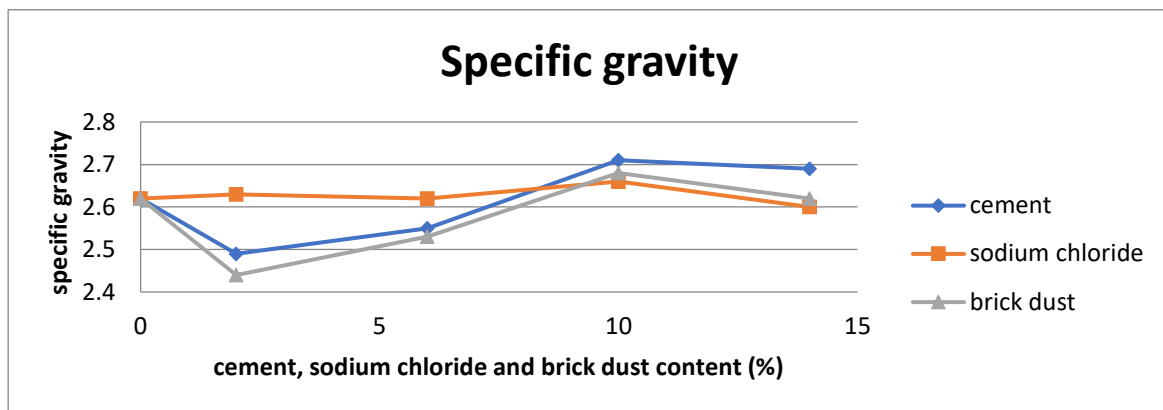


Figure 1: Variation of specific gravity with cement (%), sodium chloride (%), brick dust (%)

Higher cement content expectedly increased the specific gravity and at 14% it reduced it, also a higher sodium chloride reduces the specific gravity. Higher brick dust content increased the specific gravity and at 14% it decreases. The decrease in specific gravity at 14% is also observed for sodium chloride and brick dust.

ATTERBERG LIMITS

The test was performed to determine the liquid limit, plastic limits and plasticity index of the clay soil sample. This is done to characterize its condition by water content.

With progressive increment in percentage of cement content in the clay soil, liquid limit, plastic limit, and plasticity index all reduce but stabilizes at 14% according to Kumar *et al* in 2016.

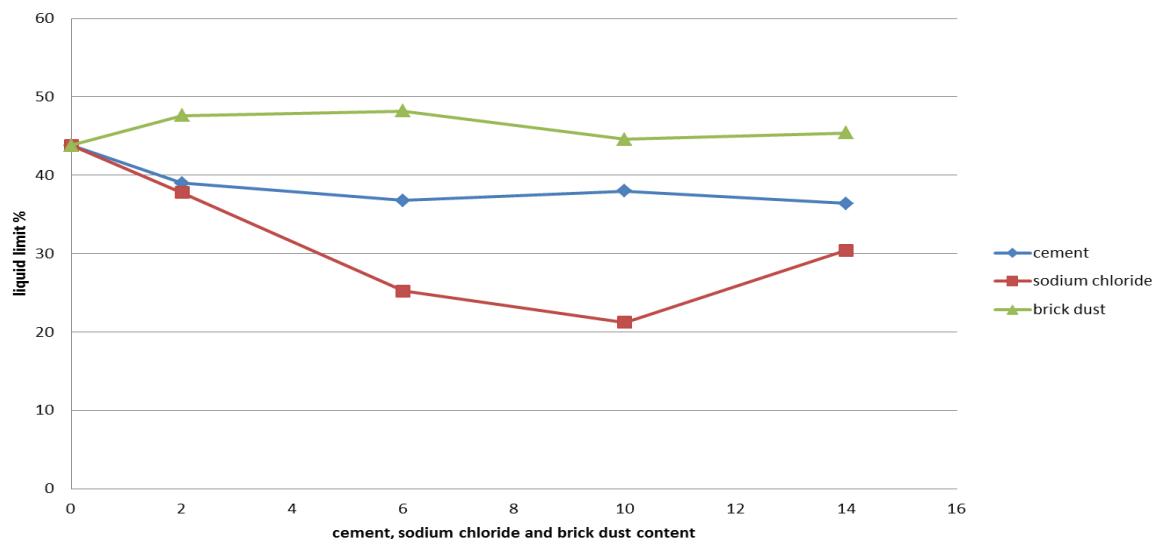


Figure 2: Graph of percentage increase of cement, sodium chloride and brick dust content for liquid limit

According to figure 2 - 4 liquid limits reduces with increase in cement and sodium chloride this is as a result the ability of cement to absorb water and the salinity in the sodium chloride while there was a decrease with increase in brick dust content this could be as a result of removal of the carbonate in fine grained soil.

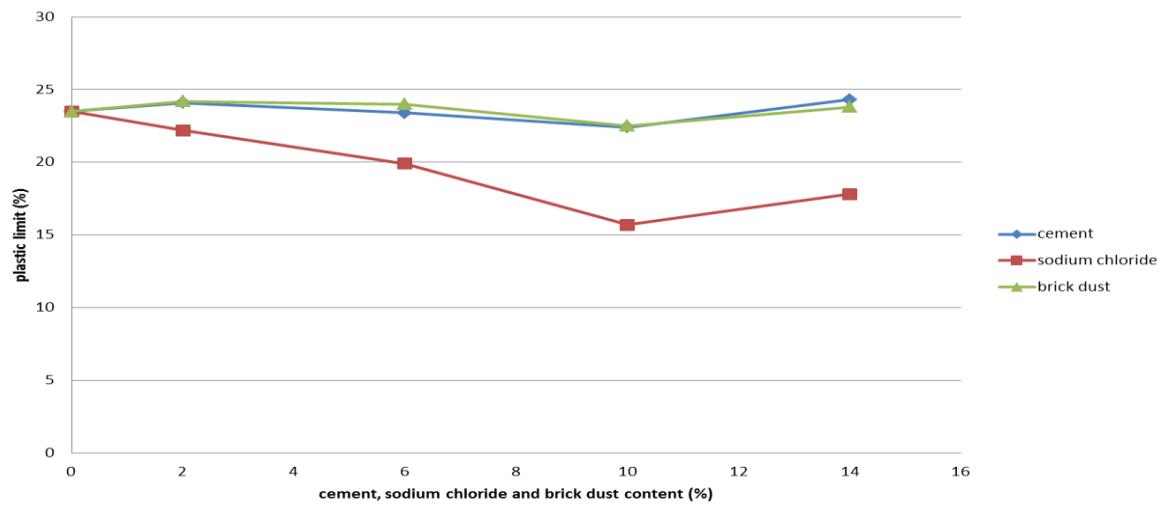


Figure 3: Graph of percentage increase of cement. Sodium chloride and brick dust content for plastic limit

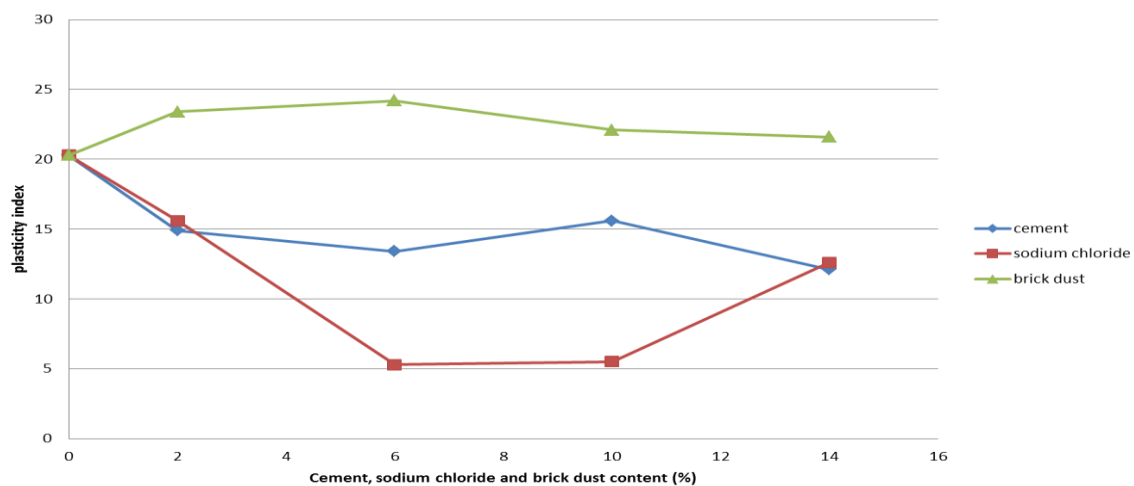


Figure 4: Graph of percentage increase of cement, sodium chloride and brick dust content for plasticity index

COMPACTION

The compaction curve of the soil sample for each 0%, 2%, 6%, 10%, and 14% cement, sodium chloride and brick dust contents are shown in figure 5 - 9. The change in OMC and maximum dry unit weight with brick dust, sodium chloride and cement content can be seen in Figures 6 to 10.

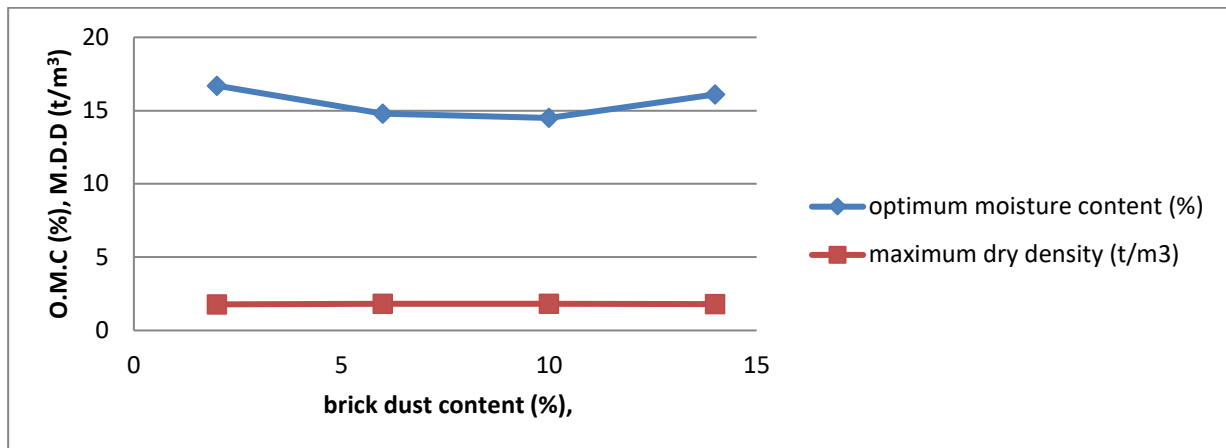


Figure 5: Variations of brick dust content based on compaction characteristics

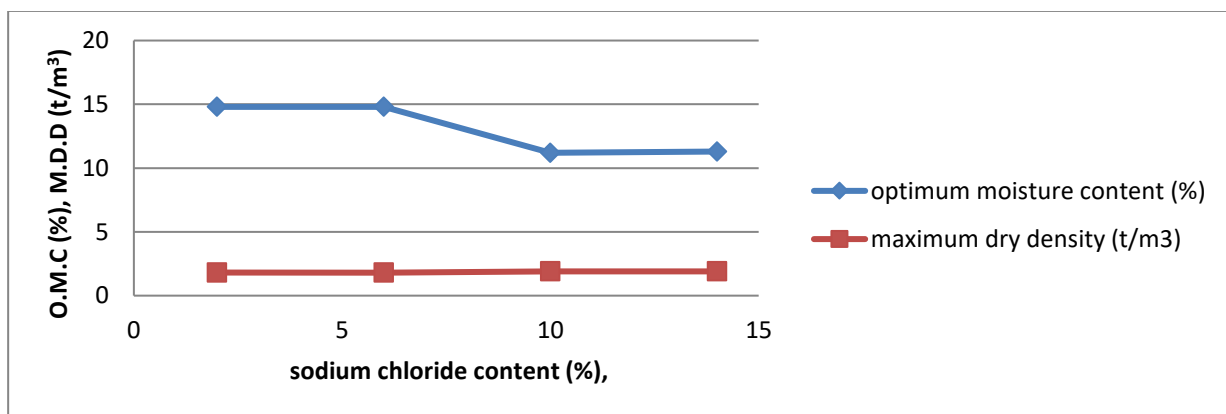


Figure 6: Variation of sodium chloride content based on compaction characteristics

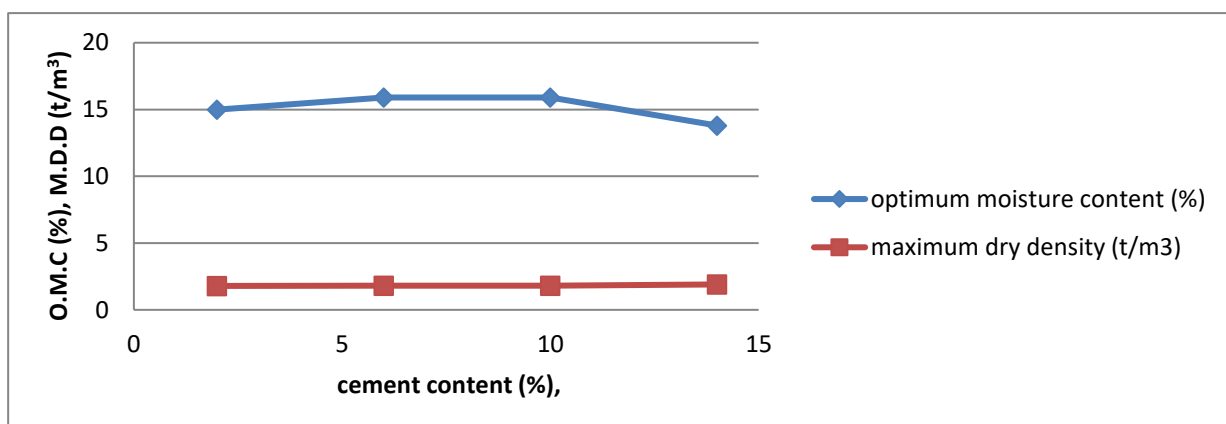


Figure 7: Variation of cement content based on compaction characteristics

The maximum dry unit weight of soil–cement mixture increased with cement contents. The maximum dry unit weight of soil-sodium chloride mixtures expectedly increased with higher salt content although was stable between 10% and 14%. The maximum dry unit weight of soil-brick dust mixtures, expectedly increased with higher brick dust content from 0%-6%, then a slight decrease from 10% to 14%.

From the figures 5 – 7, while the optimum moisture content for brick dust content is concave upward that of cement content is convex. While optimum moisture content of soil-cement mixture figure 9 decreased from 0% to 2%, then increased as the amount of cement in the mixture increased from 2% to 10% there was slight stability between 6% and 10% before a decrease for the 14% cement content. Again maximum dry density of soil-sodium chloride mixtures figure 10 decreased from 0% to 2%, showed slight stability between 2% and 6%, then a decreased at 10% and a slight increase 14%. Optimum moisture content of soil-brick dust content decrease from 0% to 10%, then increased at 14%.

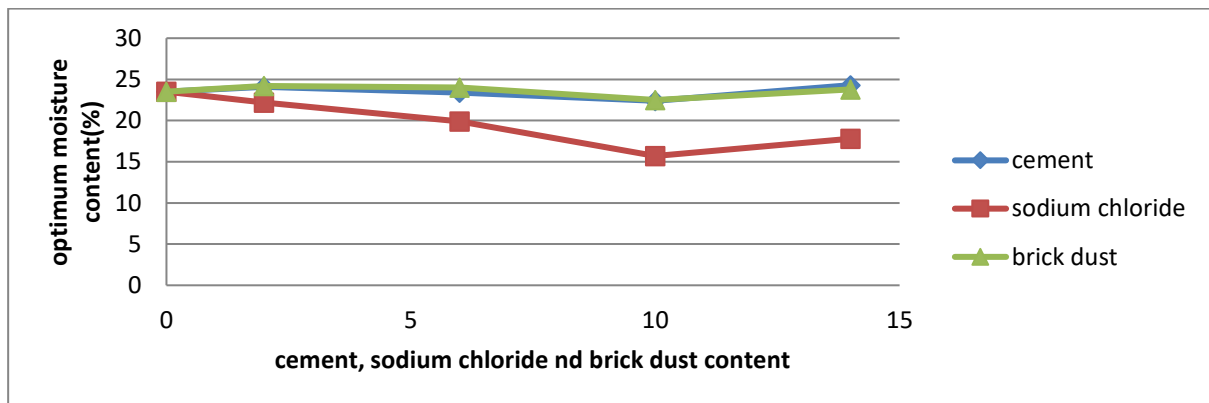


Figure 8: Variations of optimum moisture content with cement, sodium chloride and brick dust content.

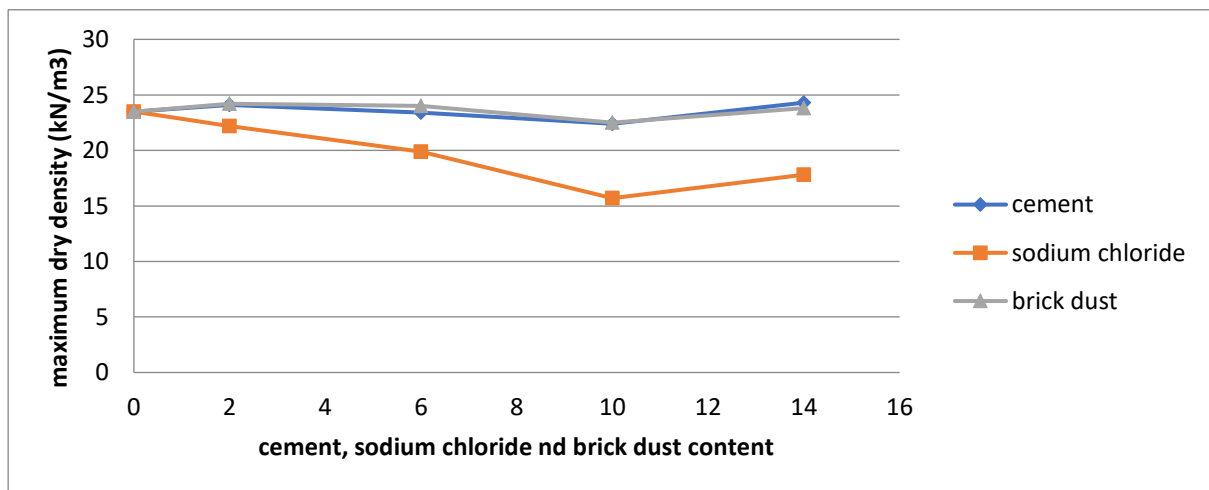


Figure 9: Variation of maximum dry density with cement, sodium chloride and brick dust content

CALIFORNIA BEARING RATIO

The change in CBR value with cement, sodium chloride and brick dust content can easily be seen in figure 10. The figure indicates that the CBR value for soil-cement mixture progressively increased from 8% for the 0% cement stabilization to 29% for the 2% cement addition, then increased to 112% for the 6% cement addition, a slight decrease to 99% for 10% cement addition, later an increase to 123% at 14% cement addition. Figure 8 also indicates that the CBR value for soil- sodium chloride mixture decreased from 8% for the 0% stabilization to 6% for the 2% sodium chloride addition, it then remain stable at 6% for the 6% sodium chloride addition, a slight decrease to 4% for 10% sodium chloride addition, later an increase to 8% at 14% sodium chloride addition.

The CBR value for soil-brick dust mixture increased from 8% for the 0% stabilizer to 9% for the 2% brick dust addition, then increased to 25% for the 6% brick dust addition, a decrease to 5% for 10% cement addition, later an increase to 28% at 14% brick dust addition. The improvement in CBR value may be attributed to change of soil structure from dispersed to flocculate.

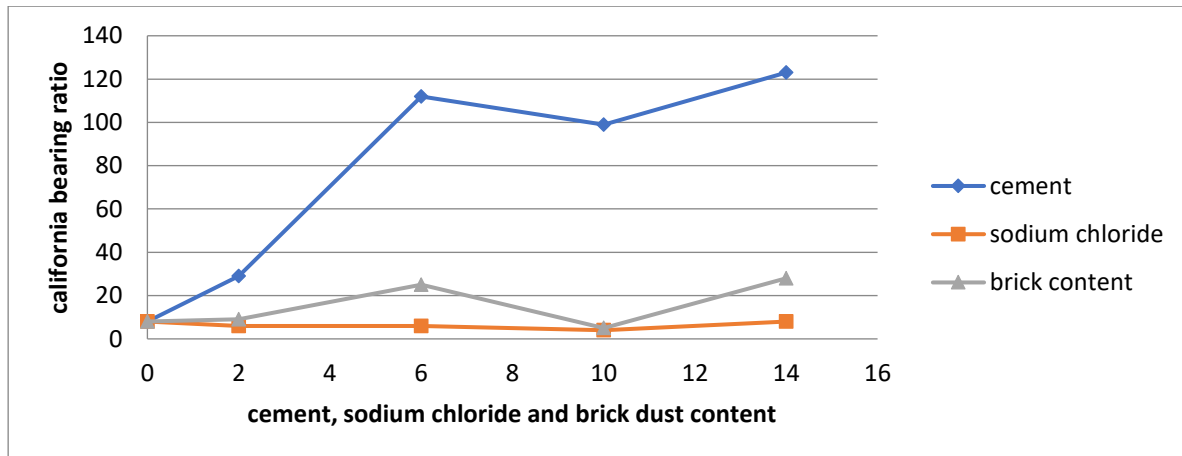


Figure 10: Variation of percentage increase in cement, brick dust and sodium chloride content for California bearing ratio.

4. Conclusion

The clay soil used in this study was classified as A-2-7 by AASTHO system or CL by USC system. The natural soil is silt clay with approximately 6.18% passing the BS No. 200 sieve. Test results generally indicate that the addition of cement and sodium chloride individually reduced the plasticity of clay soil and thereby improved its workability and reduced its moisture holding capacity and swell potential, the addition of brick dust increased the plasticity of clay soil which did not improve the workability.

Therefore, 14% optimal stabilization of A-2-7 soil with cement and sodium chloride will effectively reduce the plasticity of the natural soil to meet the requirement for use as subgrade, subbase and base course materials. Sodium chloride reduced the CBR value of the natural soil to meet the requirement for use only as subgrade material, according to Nigeria General Specification (1997). According to these results cement is the best and suitable stabilizer but because of the cost sodium chloride is more economical. More work is recommended to be done on silty clay stabilization using brick dust and brick dust lime combination at greater percentages than the 14% used in this study.

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